

COMPOSITIONS AND METHODS FOR CONSOLIDATING UNCONSOLIDATED SUBTERRANEAN FORMATIONS

Background of the Invention

1. Field of the Invention.

[001] The present invention relates to consolidating unconsolidated subterranean formations. More particularly, the present invention relates to improved resin compositions and their use in consolidating unconsolidated subterranean formations to prevent the production of particulates along with formation fluids.

2. Description of the Prior Art.

[002] Hydrocarbon wells are often located in subterranean zones that contain unconsolidated particulate matter that can migrate out with oil, gas, water, and/or other fluids produced by the wells. The presence of particulate matter, such as sand, in produced fluids is disadvantageous and undesirable in that the particulates may abrade pumping and other producing equipment and reduce the fluid production capabilities of the producing zones. Unconsolidated subterranean zones include those which contain loose particulates that are readily entrained by produced fluids and those wherein the particulates making up the zone are bonded together with insufficient bond strength to withstand the forces produced by the production of fluids through the zones.

[003] One method of controlling loose sands in unconsolidated formations involves placing a filtration bed of gravel near the wellbore in order to present a physical barrier to the transport of unconsolidated formation fines with the production of hydrocarbons. Typically, such so-called "gravel packing operations" involve the pumping and placement of a quantity of a desired particulate into the unconsolidated formation adjacent to the wellbore. Such packs may be time consuming and expensive to install.

[004] Another method used to control loose sands in unconsolidated formations involves consolidating unconsolidated subterranean producing zones into hard permeable masses by (1) pre-flushing the formation, (2) applying a hardenable resin composition, (3) applying a spacer fluid, and (4) applying an after-flush fluid containing an external catalyst activation agent to remove excess resin from the pore spaces of the formation sand and to cause the resin to set.

Such multiple-component applications, however, often result in uncertainty and create a risk for undesirable results. For example, when an insufficient amount of spacer fluid is used between the application of the hardenable resin and the application of the external catalyst, the resin may come into contact with the external catalyst in the wellbore itself rather than in the unconsolidated subterranean producing zone. This may be very problematic. When resin is contacted with an external catalyst an exothermic reaction occurs that may result in rapid polymerization. The polymerization may damage the formation by plugging the pore channels, may halt pumping when the wellbore is plugged with solid material, or may even result in a down hole explosion as a result of the heat of polymerization. Also, using these conventional processes to treat long intervals of unconsolidated regions may not be practical due to the difficulty in determining if the entire interval that has been treated with both the resin and the activation agent.

[005] Another problem encountered in the use of hardenable resin compositions is that the resins have heretofore had very short shelf lives. The shelf lives of some resins once mixed have been as short as about four hours or less. Such a short-shelf life can lead to costly waste if the operation using the resin is postponed after the resin is mixed.

SUMMARY OF THE INVENTION

[006] The present invention relates to consolidating unconsolidated subterranean formations. More particularly, the present invention relates to improved resin compositions and their use in consolidating unconsolidated subterranean formations to prevent the production of particulates along with formation fluids. The compositions and methods of the present invention involve resin compositions capable of hardening and consolidating unconsolidated subterranean regions, and substantially preventing the production of unconsolidated subterranean particles such as formation sands and fines.

[007] One embodiment of the present invention describes a resin composition comprising from about 5% to about 30% phenol, from about 40% to about 70% phenol formaldehyde, from about 10% to about 40% furfuryl alcohol, from about 0.1% to about 3% of a silane coupling agent, from about 1% to about 15% of a surfactant, and a solvent.

[008] Another embodiment of the present invention describes a method of consolidating particulates in a subterranean region comprising the steps of applying a preflush fluid to the subterranean region, applying a resin as described above to the subterranean region, and applying an after-flush fluid to the subterranean region.

[009] The objects, features and advantages of the present invention will be readily apparent to those skilled in the art upon a reading of the description of preferred embodiments that follows.

DESCRIPTION OF PREFERRED EMBODIMENTS

[010] The present invention provides improved resin compositions and methods of using the improved resins to control the production of particulates, such as formation sands and fines, along with produced formation fluids.

[011] The improved resin compositions of the present invention comprise phenol, phenol formaldehyde, furfuryl alcohol, a silane coupling agent, a surfactant, and an optional solvent. The resin compositions of the present invention may be useful in a variety of subterranean conditions but are particularly well-suited for use in subterranean formations exhibiting temperatures above about 200°F. The resins of the present invention do not begin to cure until they are exposed to temperatures above about 175°F. Thus, the resins of the present invention can be prepared and then stored for long periods of time at temperatures below about 175°F without concern that the resin compositions will become unusable over time.

[012] The resin compositions of the present invention may be used to consolidate unconsolidated subterranean formation sands. When used for that purpose, the resin viscosity should preferably be controlled to ensure that it is able to sufficiently penetrate the unconsolidated portions of the subterranean formation. For example, where the subterranean formation being consolidated is a formation surrounding a wellbore, from about 1 to about 3 feet of penetration into the formation from the wellbore may be desired. Where the subterranean formation being consolidated is a formation wall adjacent to a propped fracture, for example, from about 0.25 to about 2 inches of penetration into the fracture wall is generally sufficient. To achieve the desired level of penetration, the consolidation fluid viscosity is preferably below 100 cP, more preferably below 40 cP, and most preferably below 10 cP. Achieving the desired viscosity will generally dictate a resin to solvent ratio ranging from about 1:0.2 to about 1:20. It is within the ability of one skilled in the art with the benefit of this disclosure to use a sufficient amount of a suitable solvent to achieve the desired viscosity and, thus, to achieve the preferred penetration into the subterranean formation.

[013] One embodiment of the methods of the present invention for stabilizing a subterranean formation comprises the steps of applying a preflush solution to the unconsolidated subterranean formation, applying the resin composition of the present invention to the unconsolidated subterranean formation, applying an after-flush fluid to the unconsolidated

subterranean formation to, *inter alia*, remove excess consolidation fluid from the pore spaces and the wellbore, and then allowing time for the resin composition to substantially cure.

[014] Preflush fluids suitable for use in the methods of the present invention comprise a combination of an aqueous liquid and a surfactant. The pre-flush fluid, *inter alia*, readies the formation to receive the consolidation fluid and removes oils that may impede the consolidation fluid from making contact with the formation sands. The aqueous liquid may be fresh water, salt water, brine or any other aqueous liquid that does not adversely react with the other components utilized in accordance with this invention. Any surfactant compatible with the aqueous liquid and capable of aiding the curable resin in coating the surface of unconsolidated particles of the subterranean formation may be suitable for use in the present invention. Suitable surfactants include, but are not limited to, ethoxylated nonyl phenol phosphate esters, cationic surfactants, non-ionic surfactants, alkyl phosphonate surfactant, or combinations thereof. The mixtures of one or more cationic and nonionic surfactants are suitable and examples are described in U.S. Patent No. 6,311,773 issued to Todd et al. on November 6, 2001, the disclosure of which is incorporated herein by reference. A C₁₂ – C₂₂ alkyl phosphonate surfactant is preferred.

[015] As described above, the resin compositions of the present invention comprise phenol, phenol formaldehyde, furfuryl alcohol, a silane coupling agent, a surfactant, and an optional solvent.

[016] Phenol is a commercially available, hydroxy benzene derivative, aromatic alcohol that exhibits weak acidic properties and contains a hydroxyl group attached to a benzene ring. The resins of the present invention comprise from about 5% to about 30% phenol by weight of the overall resin composition.

[017] Phenol formaldehyde is a commercially available synthetic polymer made from phenol and formaldehyde monomers. The resins of the present invention comprise from about 40% to about 70% phenol formaldehyde by weight of the overall resin composition.

[018] Furfuryl alcohol is a primary alcohol and an oligomer of furan resin that is colorless or pale yellow in appearance. In the resins of the present invention, the furfuryl alcohol polymerizes from an oligomer form into a stable furan resin polymer. The resins of the present invention comprise from about 10% to about 40% furfuryl alcohol by weight of the overall resin composition.

[019] Silane coupling agents are chemicals that contain silicone at the center of the silane molecule that is chemically attached to a first functional group such as vinyl, amino, chloro, epoxy, mercapto, and a second functional group such as methoxy or ethoxy. Silane coupling agents act, *inter alia*, such that the first functional group may attach to an organic compound while the second functional group may attach to an inorganic material or substrate to achieve a “coupling” effect. Any silane coupling agent that is compatible with the hardening agent and facilitates the coupling of the resin to the surface of the formation sand particles is suitable for use in the present invention. Examples of preferred silane coupling agents suitable for use in the present invention include, but are not limited to, N-2-(aminoethyl)-3-aminopropyltrimethoxysilane, 3-glycidoxypentyltrimethoxysilane, n-beta-(aminoethyl)-gamma-aminopropyl trimethoxysilane, and combinations thereof. The silane coupling agent used is included in the resin in an amount capable of sufficiently bonding the resin to the particulate. In some embodiments of the present invention, the silane coupling agent used is included in the liquid hardenable resin component in the range of from about 0.1% to about 3% by weight of the liquid hardening agent component.

[020] Any surfactant compatible with the other components of the resin composition may be used in the present invention. Such surfactants include, but are not limited to, an ethoxylated nonyl phenol phosphate ester, mixtures of one or more cationic surfactants, and one or more non-ionic surfactants and an alkyl phosphonate surfactant. The mixtures of one or more cationic and nonionic surfactants are described in U.S. Patent No. 6,311,773, issued to Todd et al. on November 6, 2001, which is incorporated herein by reference. A C₁₂ – C₂₂ alkyl phosphonate surfactant is preferred. The surfactant or surfactants utilized are included in the liquid hardening agent component in an amount in the range of from about 1% to about 15% by weight of the liquid hardening agent component.

[021] Any solvent that is compatible with the resin and achieves the desired viscosity effect is suitable for use in the present invention. Solvents may be used to reduce the viscosity of the resin compositions for ease of handling, mixing, and transferring the resin composition. Preferred solvents are those having high flash points (most preferably about 125°F) because of, *inter alia*, environmental factors. As described above, use of a solvent in the resin composition is optional but may be desirable to reduce the viscosity of the resin composition. It is within the ability of one skilled in the art with the benefit of this disclosure to

determine if and how much solvent is needed to achieve a suitable viscosity. Solvents suitable for use in the present invention include, but are not limited to, 2-butoxy ethanol, butylglycidyl ether, dipropylene glycol methyl ether, dipropylene glycol dimethyl ether, dimethyl sulfoxide, dimethyl formamide, diethyleneglycol methyl ether, diethylene glycol dimethyl ether, ethyleneglycol butyl ether, diethyleneglycol butyl ether, gamma-butyrolactone, butylene carbonate, propylene carbonate, ethylene carbonate, methanol, butyl alcohol, d'limonene, fatty acid methyl esters, and combinations thereof. The amount of the solvent utilized in the resin composition is generally in the range of from about 0% to about 300% by weight of the resin composition.

[022] The after-flush may be an aqueous liquid or an inert gas. Where the after-flush fluid is an aqueous liquid, it may be fresh water, salt water, brine, viscosified water, or any other aqueous liquid that does not adversely react with the other components utilized in accordance with this invention. Where an aqueous after-flush fluid is used, a volume of about 1 to about 5 times the volume of the consolidation fluid used is generally suitable. In some subterranean formations, particularly gas-producing subterranean formations, it may be advantageous to after-flush using an inert gas, such as nitrogen, rather than an aqueous solution to prevent interaction between the after-flush fluid and the formation. The after-flush fluid acts, *inter alia*, to displace the curable resin from the wellbore, to remove curable resin from the pore spaces inside the subterranean formation thereby restoring permeability and leaving behind some resin at the contact points between formation sand particulate to form a permeable, consolidated formation sand pack.

[023] The chosen period of time needed for the resin to substantially cure will depend on the consolidation fluid used, the temperature of the formation, and the unconfined compressive strength needed in the particular application. Generally, the chosen period of time will be between about 0.5 hours and about 72 hours, preferably between about 6 hours and about 48 hours. Determining the proper cure time is within the ability of one skilled in the art with the benefit of this disclosure.

[024] To facilitate a better understanding of the present invention, the following examples of some of the preferred embodiments are given. In no way should such examples be read to limit the scope of the invention.

EXAMPLES

Example 1

[025] Unconsolidated formation sand packs were simulated by preparing a mixture of 70/170-mesh sand (88% by weight) with silica flour (12% by weight). This sand mixture was tightly packed into a cylinder brass chamber having a diameter of 2.38 cm. The sand pack was sandwiched between two sand packs of 20/40-mesh sand, each with a thickness of 1.25 cm. A 80-mesh stainless wire-mesh screen was also installed at the bottom of the sand pack. The overall length of the sand pack was 9.85 cm. A low viscosity phenolic-furan resin of the present invention was prepared by mixing 9.5 mL of phenol, 78 mL of phenol formaldehyde, and 32.5 mL of furfuryl alcohol, 180 cc of 2-butoxy ethanol, 3 cc of n-beta-(aminoethyl)-gamma-aminopropyl trimethoxysilane, and 15 cc of an alkyl phosphonate surfactant.

[026] The treatment procedure involved injecting the sand pack with 100 cc of preflush which comprised of 5% NH_4Cl and 1% alkyl phosphonate surfactant, injecting 100 cc of low viscosity phenolic-furan resin mixture, and injecting 200 cc of afterflush which is the same as that of the preflush. The resin-treated sand pack was then sealed to prevent leaking or evaporation during curing and was placed in oven for curing at 275°F for 40 hours. After curing, consolidated cores were obtained for unconfined compressive strength measurements. The unconfined compressive strengths are ranging between 450 psi to 975 psi.

[027] Therefore, the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned as well as those that are inherent therein. While numerous changes may be made by those skilled in the art, such changes are encompassed within the spirit and scope of this invention as defined by the appended claims.